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DESIGN AND DEVELOPMENT OF A MULTI-CONFIGURATION BEAM VIBRATION TEST SETUP

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ABSTRACT

Over last few decades, significant work in the area of beam vibrations is reported. Uses of classical beam theories have been implemented to study the modal characteristics viz. mode shapes, frequency and damping. The change of modal characteristics provides an indication of structural condition based on changes in frequencies and mode shapes of vibration. This needs to be checked theoretically and validated experimentally with the specimens. In the present work, a setup for the beam vibrations with different configurations is developed economically. The setup can check many key parameters of beam vibrations. Further a case study is presented, whereby cantilever beam specimens with different materials are checked using FFT analyser on the setup developed and the results are validated using ANSYS package.

Key words: ANSYS, Cantilever Beam, FFT Analysis, Modal Analysis, Vibration Analysis.

1. INTRODUCTION

Vibration analysis is very significant from the design point of view. It gives an idea about the dynamic behaviour of the structural elements in the actual harsh working environments. The information collected from the vibration data helps the designer to make the necessary changes in the design to avoid the resonance condition of extreme amplitude of vibration, thereby increasing the reliability of the system. So it is imperative to design the system prior to installation to avoid its vibration born failures. Beam structures find widespread applications. They are found in various configurations like fixed-fixed, fixed-free, overhang, continuous etc. as per the application. The parameters for all such configurations differ from application to application. Thus it is needed to check and examine the key parameters with direct bearing on the dynamic behaviour of the system.

Recently, the experimental modal analysis (abbreviated as EMA) or simply modal testing has gained admiration. It has become an effective means for identifying, understanding and simulating dynamic behaviour and responses of structures [1]. EMA is a non-destructive testing technique based on vibration responses of the structures. One of the frequently used technique in EMA is impacting the structure by using a wooden mallet or impact hammer to excite its natural frequencies. The frequency response functions (FRFs) are captured using the Fast Fourier Transform technique (FFT) using a suitable transducer and FFT analyser. Figure 1 shows the typical schematic diagram of the EMA technique. For successful implementation of the EMA for analysing the various key parameters of the different beam configurations, a multi-functional setup for the experimentation with provisions for all such configuration is required to set a benchmark in the data acquired. Moreover, it facilitates same boundary conditions to be incorporated in experimentation for all the specimens for assessment. In short, there must be repeatability in producing the same clamping forces to incorporate same boundary conditions for different specimens so as to minimise the errors. To achieve this, the work of setup development is undertaken to facilitate further studies on it.

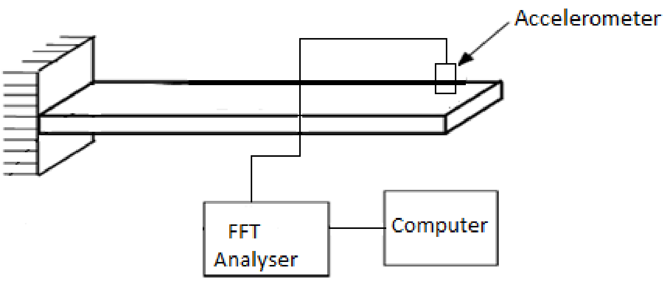
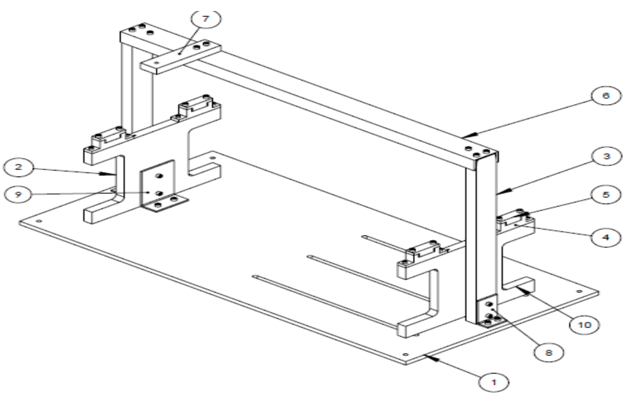


Fig.1schematic diagram of the setup [2]

2. DEVELOPMENT OF THE SETUP

As mentioned, a setup with all the possible provisions for the study of beam vibrations with different configurations is developed. Mild steel is selected as the material for the parts of setup as it has higher density, high energy absorbing capacity and economical availability, and also provides rigidity to the structure. The approximate weight of the setup is 180 kg. Due care has been taken towards the geometrical tolerances and aesthetics while designing and manufacturing the setup. Figure 2 shows the part details of the setup and figure 3 shows the CAD model of setup developed.



Sr. No.	Part Name
1	Base Plate
2	I-Section(Left)
3	Column
4	Beam Support
5	Beam fix plate
6	C-channel for frame
7	Provision for torsional module
8	Column support bracket
9	I-Section support bracket
10	I-Section(Right)

Fig.2 part details of the setup developed

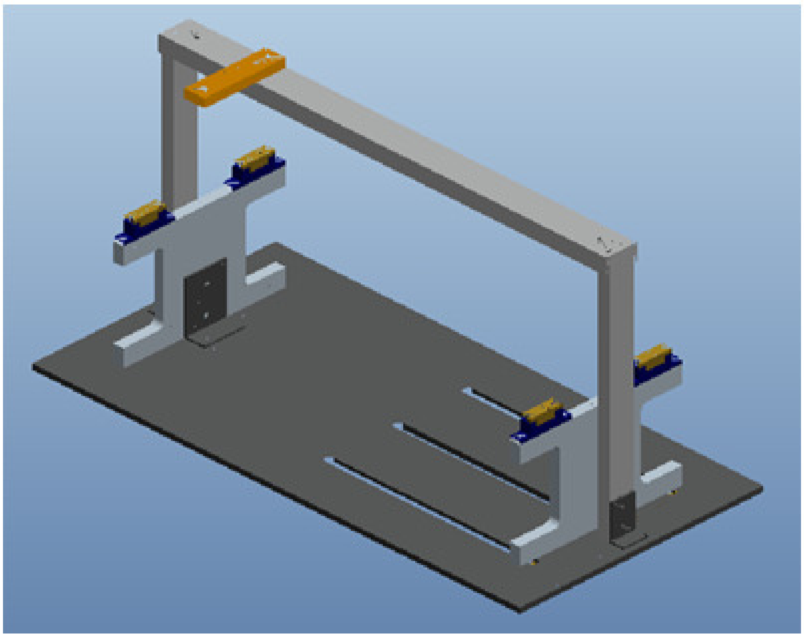


Fig.3 CAD model of setup developed

2.1. Features

The setup can house different beam configurations like cantilever, overhang, simply supported with a span length from 0.5 meters up to 1.125 meters. The beam specimens of width up to 50mm can be mounted on the setup with an additional provision up to 75mm width. Also a torsional vibration module (free and forced) is developed along with the beam vibration module. An additional provision of varying the shaft diameter from 1 mm up to 10mm is made in the setup which is not available with the commercially available setups.

The main feature of the setup along with the features provided in it is its economic costing. It is manufactured, developed and installed at about 50% cost of commercially available setups. It is provided with the features that are not available in existing commercial versions. Due care has been given to aesthetics while modelling and manufacturing the setup.

3. THEORETICAL BACKGROUND OF BEAM VIBRATIONS

The frequency of a simple uniform cantilever beam with rectangular cross section can be obtained from the following equation:

$$\omega_n = \frac{1}{2\pi}(\beta l)^2\sqrt{\frac{EI}{\rho A L^4}} \quad \textbf{(1)}$$

Where,

A is the area of cross section of beam, L is the length of the beam, ρ is the density of material, EI is the equivalent bending stiffness and βl is the constant relative to the vibration bound condition [3][4].Using the formula, we can derive the fundamental mode shape frequencies of the beam specimens of different materials.

4. EXPERIMENTAL INVESTIGATION

The cantilever beam configuration is selected on the setup developed with varying the material of specimens. Specimens used are of mild steel, aluminium and isotropic polymer.

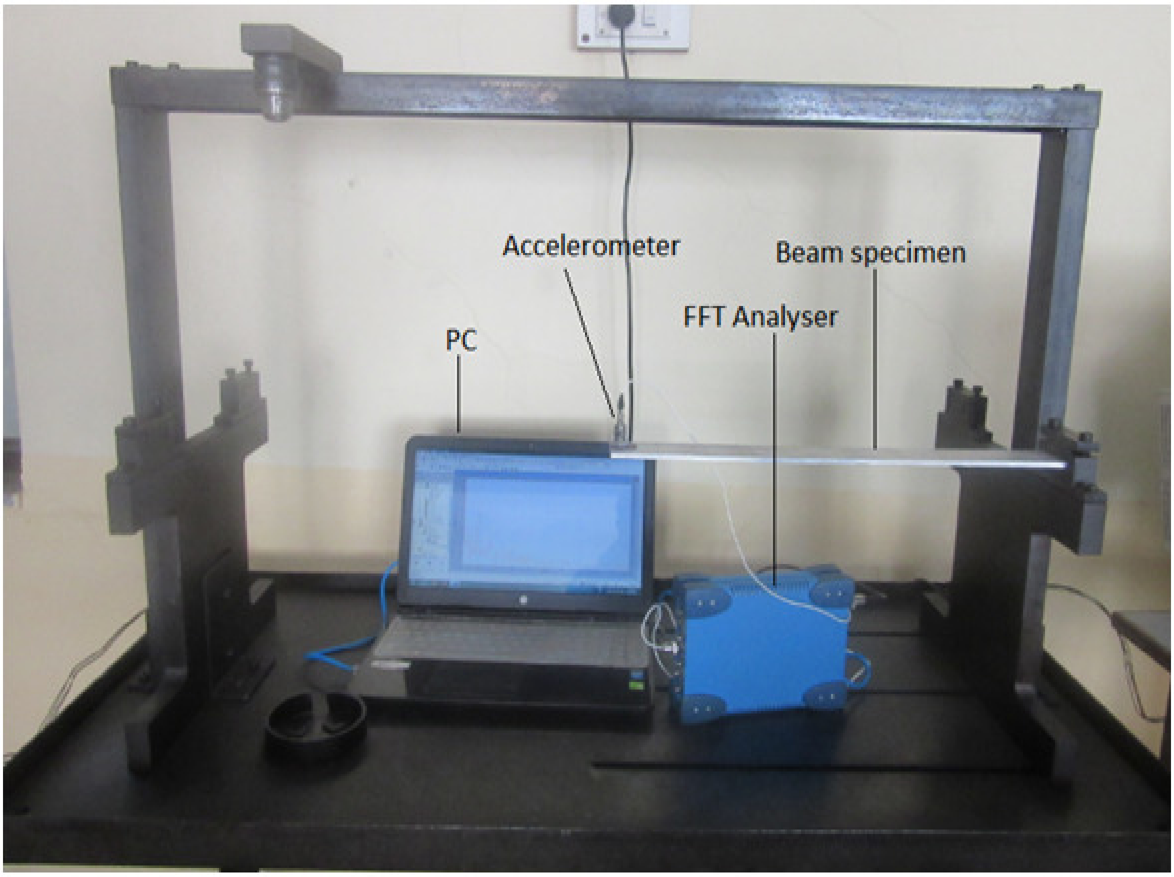


Fig.4 actual testing arrangement with cantilever specimen

The instruments used in this study are the OROS made 4-channel FFT analyser, and an accelerometer with magnetic base.

4.1Specifications of FFT Analyser

- Made- OROS OR34
- Channels- 4 channel per plug-in for online and post analysis.
- Range- 512 mHz to 25.6 kHz
- Max FFT lines- 6401
- Sampling- 102.4 kS/s to 3200 S/s with 24 bit sigma-delta ADC.
- Coupling- AC, DC, ICP, AC & DC float, GND
- Sensitivity- User defined in mV/unit.

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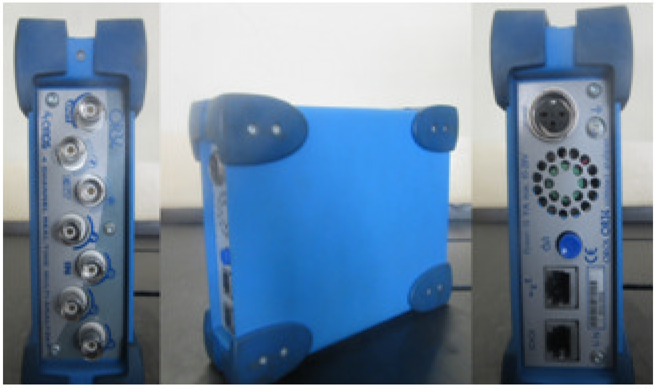


Fig.5 FFT analyser with front and back panel

Fig.6 accelerometer

4.2Accelerometer Specifications

- Made and model- DYTRAN 3056B2.
- Acceleration- -50 to 50 g.
- Frequency Range- 1-10000 Hz.
- Accuracy- 2.0 +/- % FS
- Measurement Axes- Single
- Reference sensitivity- 103.7 mV/g.

A wooden mallet is used to impact the beam at free end. Necessary input settings and analyser settings are made on the OROS analyser in order to obtain good frequency response functions (FRFs). The hardware is connected to the computer using the NV Gate software provided with the FFT. A typical response of the FFT is as shown in the figure 7.

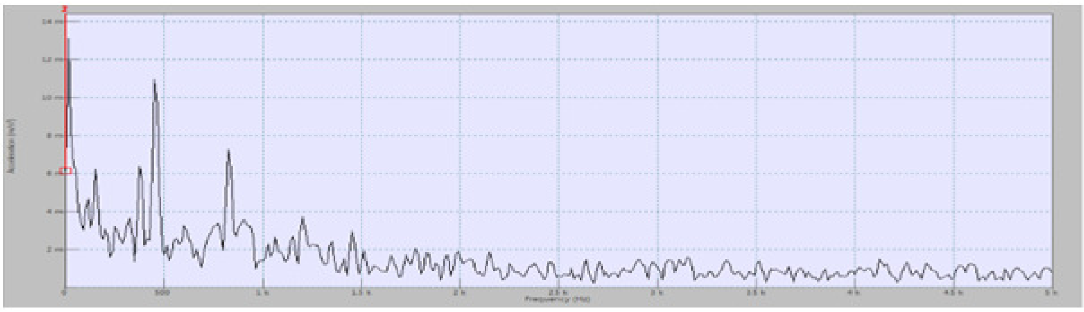


Fig.7 typical FFT response with NV Gate and FFT analyser

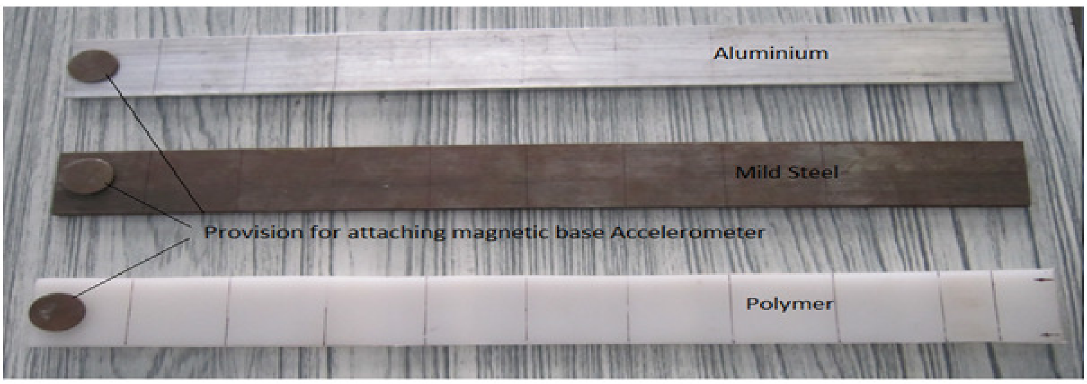


Fig.8 test specimens used

Beam specifications used for the work undertaken are tabulated in TABLE 1:

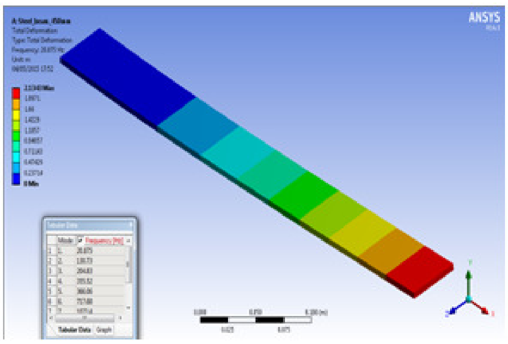
Table 1: Material specification

Material	Length mm	Width mm	Thickness mm	Density kg/m^3	Young's Modulus GPa
Mild steel	450	50	05	7850	210
Aluminium	450	50	05	2700	75
Polymer	450	50	05	900	1.223

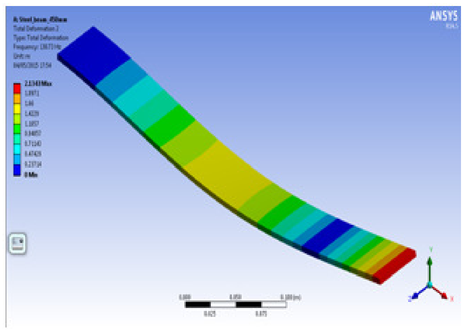
FRFs for all the specimens are taken using the analyser and compared with the theoretical values obtained using equation (1) and the one obtained with ANSYS 14.5 Workbench module.

5. MODAL ANALYSIS USING ANSYS

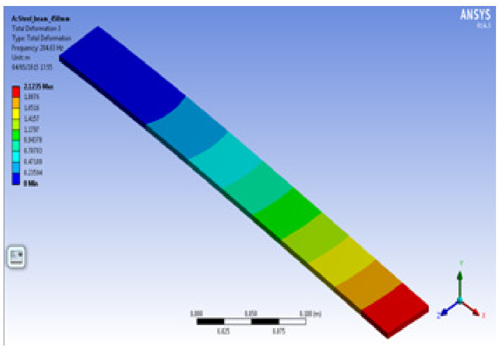
For performing the modal analysis, the beam specimen is first modelled as per the dimensions using the Pro-E Wild Fire 5.0 modeller. The IGES file of the geometry is then imported in the ANSYS 14.5 Workbench. One of the end of beam is constrained as fixed end and other is kept free. A mesh with 200 elements and 1628 nodes is applied and Solid185 element is used. The block lanczos mode extraction method is implemented and total of first ten number of modes are extracted and expanded in the Workbench. Following figures shows the results obtained from the simulation for the first three modes of the cantilever mild steel, aluminium and polymer specimens.



(a)

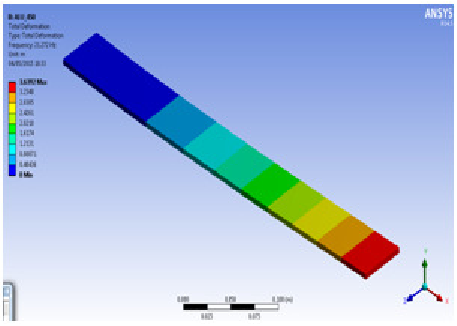


(b)

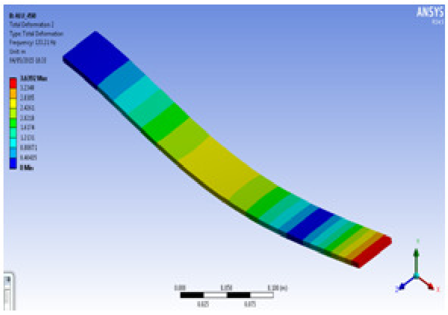


(c)

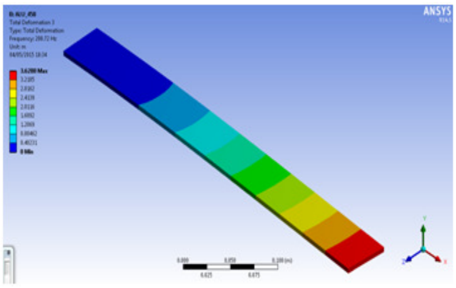
Fig.9 modes of vibration for steel beam (a) 1st mode (b) 2nd mode (c) 3rd mode



(a)

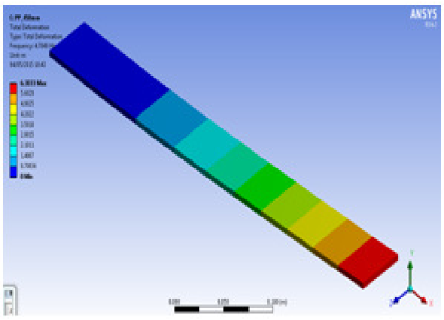


(b)

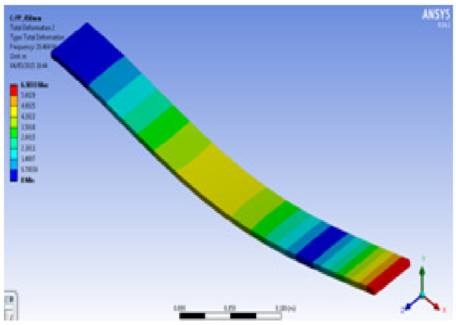


(c)

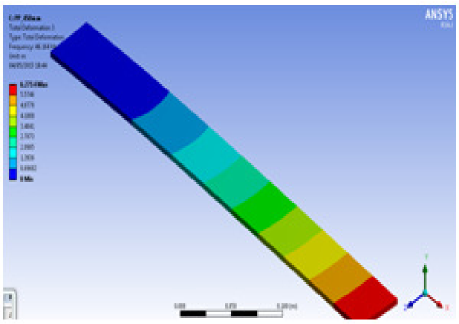
Fig.10 modes of vibration of aluminium beam (a) 1st mode (b) 2nd mode (c) 3rd mode



(a)



(b)



(c)

Fig.11 modes of vibration of polymer beam (a) 1st mode (b) 2nd mode (c) 3rd mode

6. RESULTS AND DISCUSSION

Thus the study of the free vibration of the cantilever beams of different materials viz. mild steel, aluminium and isotropic polymer is carried out satisfactorily on the setup developed. Theoretical, numerical and experimental approach is used to calculate the modal frequencies of the specimens. Results are found to be in good agreement with each other. The discrepancies in the results may be due to the material in-homogeneity, loading effects, numerical error built in the software etc. Following table shows the results obtained. The data is compared and tabulated for the first three modes of vibration. Graph shows the comparison of the FEA results for first ten modes of vibration of three specimens.

Table 2: Theoretical, numerical and experimental results

	Theoretical								
	Classical Theory			FEA			Experimental		
	1st Mode	2nd Mode	3rd Mode	1st Mode	2nd Mode	3rd Mode	1st Mode	2nd Mode	3rd Mode
M.S	20.62	129.28	362.02	20.69	130.73	204.83	22.5	125	212.5
Aluminium	21.01	131.73	368.9	21.27	133.21	208.72	18.5	112.5	185.5
Polymer	4.64	29.13	81.59	4.704	29.464	46.164	6.5	33	57.5

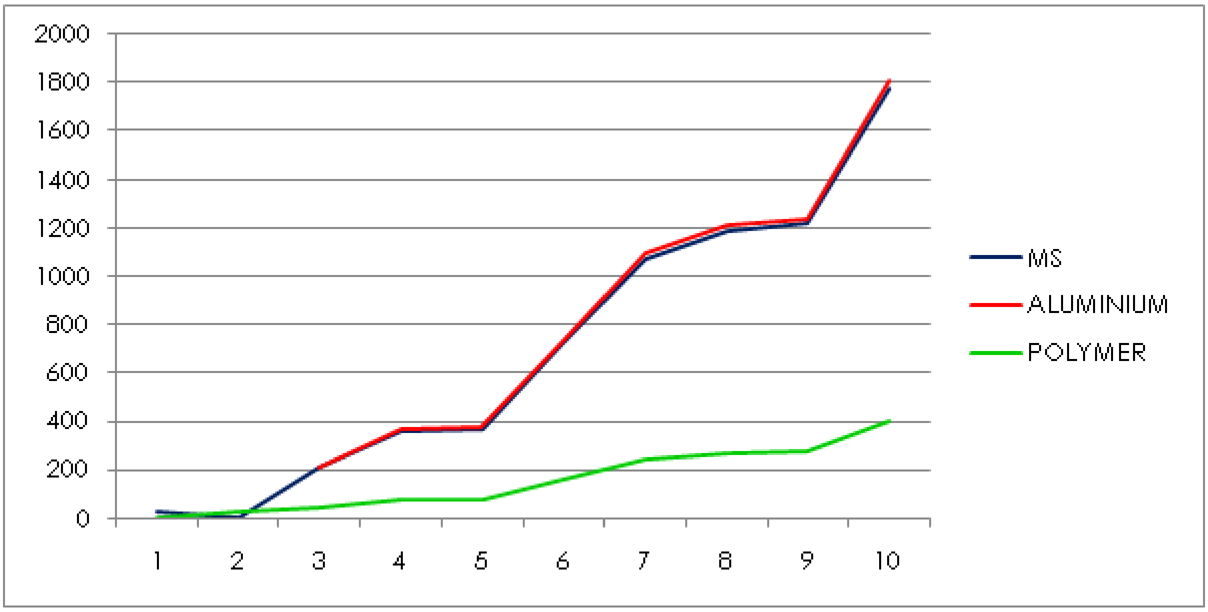


Fig. 12: mode shapes for specimens (mode shape vs. frequency)

7. CONCLUSION

Thus a multi-configuration beam vibration setup is established at around 50% cost of commercially available versions and with additional features. Also a Non-Destructive method for cantilever beam vibration study with three different materials is successfully carried out on the setup and the results obtained are in good agreement with the theoretical and numerical (FEA) results.

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